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I. INTRODUCTION

We were charged in essence with the problem "Is something wrong with C/M and if so, what?"

The first step in coming to grips with this question is to agree to methods for evaluating the system. Since the end result is a photographic image we must construct an objective quantitative measure of image quality. Against this standard the performance of the system must be measured and the observed image compared with the one to which the system is designed - including effects of atmosphere, image motion and film processing and sensitivity in addition to the lens system.

If all of these factors are fully understood and the design performance is achieved, then we conclude C/M is a satisfactory system in the sense we have given it a test and it has passed. There is a big question of course: have we given the right test, i.e., the most useful one from the viewpoint of the mission we want C/M to accomplish? In more specific terms we speak of the optical transfer function or the sine wave response curve t (k) as a function of spatial frequency k as the most convenient meeting ground between design and performance. In the engineering design of an optical system one seeks maximum resolution in lines/mm by keeping t (k) as large as possible in the region of high k.

It is the primary concern of this Committee to determine to what extent the design t (k) is achieved by the system in practice. On the other hand, there are users' criteria of quality and one might benefit for intelligence purpose by trading off, for example, some resolution in order to achieve higher contrast - this is a human factor involving the PI's. This question

of the optimum design of a transfer function for the intelligence community is a corollary and also vital problem.

The distinction between user criteria and engineering criteria cannot be overstressed. In the first case on typically asks, "Is photographic sample A a better source of intelligence information than sample B and if so by how much?" In the second case one asks, "Is the equipment performing in actual use as it did under laboratory test and if there is a difference what is the magnitude of the difference?"

We discuss first in this report the question of constructing an objective measure of image quality that is both useful and experimentally feasible. In practice, in the real world, there are many parameters affecting the performance which cannot be precisely specified. The transfer function t (k), is a product of four components:

$$t\,(k) = t\,(k)_{\text{atmosphere}} \quad t\,(k)_{\text{image motion}} \quad t\,(k)_{\text{optics}} \quad t\,(k)_{\text{film}},$$

and uncertainties in these individual factors make it impossible for us to say that the system passes any test perfectly.

We also recognize that this characterization of performance by t (k) is incomplete since granularity is not taken into account. In these discussions we assume the slow, fine grained film 4404 now in use is a fixed parameter of the system.

Rather we must content ourselves by reporting it to perform within a certain quality range. The more we can sharpen up the individual factors the more precise will be our understanding of the system. This calls for a Measurement Program - which is the next main subject of discussion in this report. Engineering passes over known design targets in known weather conditions are one aspect. Another very important one is an in-flight measurement program to determine, for example, what the effect of the in-flight

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environment is on the optical focus - one area of particular concern being the possible focal errors introduced by thermal gradients and transients in the camera barrel and lens system. We do not here attempt a detailed design study but we indicate the types of measurements felt to be most desirable and which can be made on ground or in orbit without substantially conflicting with the operational goals of the C/M missions.

As a general remark we add our very strong conviction of the need for instituting with great urgency a program of mission measurements and analyses to help identify the causes degrading most of the image quality obtained thus far - or to verify by establishing a lack of correlation between the image quality and the monitored parameters that the present quality is typical of what is to be expected. The measurement programs proposed in this report should be carefully prepared and not viewed as quick fixes.

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II. SUMMARY AND RECOMMENDATIONS

A. Objective Measures of Image Quality

1. Edge measurement techniques for determining the optical transfer function.

   The aim here is to provide a reliable and reproducible "canonical" technique for accurately measuring t (k) particularly for high spatial frequencies (say 10 ft ground resolution or 100 L/mm). We want to know t (k) for two reasons. By comparing the measured t (k) with the value to which the system is designed we can hope to answer whether the photography obtained is all that can be expected from C/M or whether there is a loss of resolution due to shortcomings of the system. Since the atmosphere's transfer function enters into this comparison it too must be measured or calculated

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In view of the extremely limited technical feed back as to the performance of components in flight to the systems designers, it is amazing to those of us on the "outside" how well C/M has done so far. Nevertheless, there are major quality variations which follow no understood pattern from one mission to the next. In its best moments C/M has performed very well, indicating that improvements to a higher level of reliability should be possible. The urgency of a measurement program and of timely systematic performance analyses to enable the designers to achieve possible improvements cannot, therefore, be overemphasized.

in principle. As discussed further in Section D the only significant effect of atmospheric haze on C/M photography 7 is a DC reduction of contrast and therefore resolution although the form of ~~and~~ t (k) is independent of this and therefore of the atmosphere.

The practicability of microdensitometric edge measurements for a routine evaluation of photography at high resolution in order to determine t (k) must still be established. As a relatively new technique it is still fraught with practical difficulties and potential dangers. It presents no theoretical problems, however. Suitable edges for the scale of C/M photography are found in nature in the form of large airfield landing strips and for special tests can be conveniently provided by a target layout on the ground.

In order to demonstrate practicability of edge measurements for 100 Lines/mm analysis a long-range industrial program is in progress and full support to continue and expand it is recommended. Its developm ent goals should be to

1) Establish reliability by comparing recent measurements of t (k) from edge scans to results from sine wave targets. The resulting modulation transfer function should be combined with a film modulation threshold curve to predict the resolution in Lines/mm for direct experimental comparison.

2) Compare and standardize different μ-densitometer slits, determining optimal dimensions and data handling methods.

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3) Determine practicability of the method in terms of number of man-hours involved per edge for a reliable scan.

Toward these ends we recommend that there be

1) Initiated both at Westover and NPIC a program of selecting and measuring edge on new mission material (and on past material if warranted by success of the above program) both to advance the confidence in and reliability of edge measurements and to accumulated data on C/M performance. At this time we do not believe the edge scan method is ready for production use; and

2) Constituted a working group including representatives of principal laboratories to carry out a standardization study on edge measurement techniques. This activity should not be bound by security restrictions but should operate as an industrial cooperation oriented by a work statement for such a study for this Committee.

2. Visual comparison of photography of unknown quality with photography of known quality as obtained by the same optical system.

This technique of subjective quality comparators or "GEMS" (Graded Estimated Measuring Samples) for judging image quality is of interest and potential value because there are no standard resolution targets in operational photography and the edge scan measurements are still of uncertain merit. Moreover comparative

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analysis of properly prepared GEMS may provide some valuable input into a human equation for the optimum photography for use of the intelligence community.

Both the flexibility and quantitative value of GEMS are uncertain at this moment and experience in working with them will be important in evaluating this technique.

The first use of such photographic comparators is for engineering evaluation. They will be designed with the aim of permitting the observer to identify the main characteristics of quality degradation in the actual picture - whether due to reduction of t (k) for high k leading to fuzzy edges of high contrast, or non-optimal processing to high or low average densities which affects graininess, or loss of contrast (due to the ~~seam~~ sum of the effects of corona discharge, light leaks, haze, and thin clouds) but with edges remaining sharp. The observer will identify these quality characteristics by comparison with a library series of GEMS that can be brought to adjacent positions in sequence by a comparison eyepiece. He can also rate the photography by a resolution level in L/mm for 2:1 contrast targets as imaged in the GEMS.

The second use would be to determine the effects of the variables introduced into the GEMS on the value of photographic material for intelligence purposes. To reiterate an earlier point - our primary Committee concern is to determine how well the system produces its design transfer function, but the question of what the transfer function to which the system is to be optimally designed is a longer-ranged and corollary question, and is discussed in the technical sections.

A comparison technique for assessing the photographic quality is presented and the basic elements of a GEM library are discussed in this report. As a first step in implementing this program a simple dual microscope system with a comparison eyepiece and a small library of GEMS with varying resolutions has been prepared.

3. <u>First results of Edge Scan Measurements and visual photographic comparators applied to operational photography</u>.

Edge scan measurements on mission photography have been made with the Eastman Kodak μ-densitometer as summarized in Figures 1, 2, and 3 where the resolution in L/mm is computed from the measured transfer function for 2:1 contrast targets.

GEM measurements of the limiting resolutions of scenes in the close vicinity of these edge scans were made and the correlation with the edge scan results shown in Figure 4. That no better than a moderate degree of correlation was found indicates the extreme caution with which these first results must be viewed.

The 77 frames of Mission 9056 which were given subjective MIP (Mission Information Potential) rating at NPIC and as discussed and plotted by [redacted] caused very great concern, were compared with the GEMS as shown on Figure 5. A lack of correlation is evident - as it is also with the RES (Reciprocal Edge Spread)measurements made at Westover (Figure 6). Furthermore, these two different subjective measures of quality, RES and MIP, fail to correlate with each other as shown by Figure 7. The conclusion from this is that both MIP and RES measurements have a presently uncertain, if indeed any, quantitative value.

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The lack of correlation of RES with edge scan measurements can in part be attributed to the sensitivity of the RES results with the average density of exposure. At this time we see no quantitative value to RES and therefore no reason for continuing a program of measuring RES values.

In assessing image quality by subjective standards we believe that variations in the illumination conditions contribute significantly to the observed spread of quality although we have not assessed the significance of these variations quantitatively. Figures 8 and 9 show two striking examples of this effect in technically equivalent pairs of photographs. Only the angle of solar illumination is different in Figures 8 and the angle between viewing directions and illumination in Figures 9. The actual shadows are the same in Figs 9 which show two successive frames 10 seconds apart along a flight line but the extent to which they are viewed depends strikingly in the camera's angle of view.

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It is also clear that factors which increase? reduce the relative brightness of the shadows such as haze and scattered clouds will tend to dilute the above effects, so as to make the photography generally drift in quality toward the low contrast of the subsolar point seen in Fig. 9. Indeed ~~the effect of~~ moderate haze in scattering light into the shadows has a ~~probably~~ a ~~more~~ significant effect on overall quality in addition to ~~than~~ the DC back-scattering of light into the lens. Clouds can produce a similar effect even though a ground target is directly illuminated by the sun and directly visible by the camera.

These factors which play an important role in subjective evaluations are not relevant in an engineering analysis of a system in terms of limiting resolution in L/mm. If one is to compare objective and subjective measures of image quality such as MIP values then a way must be found to take into account the effect of variability of subject matter.

The GEM and edge scan measures show some promise but conclusions at this time would be premature and the question of C/M's performance is still to be decided by continued analyses by edges and scans and GEMS. Mission 9062 is now being analyzed by edge scan and GEM ratings and results obtained so far are summarized in Figures 10 and 11.

Beyond determining a level of average performance in terms of limiting resolution in L/mm for 2:1 contrast targets we would like to determine a mean spread in performance about this

average. Neither the edge scan nor GEM measurements have advanced yet to the level that we can with any confidence deduce this spread from observations. Moreover in the absence of a detailed measurement program on in-orbit physical parameters, the anticipated spread in performance cannot be computed accurately.

The potential values of GEMS for relating the physical characteristics of the photographic image with its intelligence value to the PI remains to be explored and further work in this direction is recommended.

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B. Measurement Program

1. In-flight measurements for obtaining engineering data to check on system performance in the operational environment and to correlate with image quality.

The C/M system is subjected to extensive laboratory tests on the ground in Boston, Palo Alto, and Vandenberg to check its operation both before and after thermal and pressure changes, in different gravity orientations, and after vibrations. These tests are designed to cover the range of parameters anticipated during launch and orbital phases and focal settings must still be within tolerances.

There is no way of knowing, however, that focal errors resulting from thermal gradients and transients do not degrate actual system performance in flight. No in-flight measurement program exists for determining the temperature inhomogeneities during flight due to variable sun angles and camera barrel exposure to space, and furthermore, there is no in-flight verification that the focal point is at the film. Remedies for these deficiencies are proposed.. They require a continuing in-flight measurement program not seriously interfering with operational activities and designed to:

a) locate the focal point relative to the film and

b) measure local temperatures of the level.

Furthermore, a vigorous and more thorough laboratory study with a theoretical model is encouraged to complement this program, providing more details as to where to put temperature sensors on board and pointing the way toward improved thermal control.

Additional ground tests over a broader range of parameters for checking film flatness are suggested. These should include a broad temperature range and should be designed to test vibration and post acceleration effects.

Another recurring plague of C/M photography is corona discharge. Laboratory tests suggest that if the film were maintain at a pressure of 20 to 100 instead of at ambient this condition would be controlled. Work is in progress to develop a light weight pressure system and should be pressed with full support. In view of the recurring serious corona problem a suitable system for maintaining pressures above 20 even if not at optimal one, should be introduced in C/M as soon as possible, along with periodic pressure monitoring.

Direct tests on film properties and sensitometry are discussed in Section C.

2. <u>Engineering passes with daylight photography of design aerial targets.</u>

It is recommended that these be carried out and the present program extended until one is driven to the conclusion that the system is working up to its design potential. Simultaneous recording of component performance in the measurement program described in the preceding section is necessary to permit degraded imagery to be correlated with faulty components. The resulting loss of operational coverage resulting from such a program is ~~both~~ not ~~in~~significant and is a very worthy investment.

A minimal aerial target is designed which permits determination of the transfer function t (k) from edge measurements on the scale of C/M photography as well as for any system of comparable or superior resolution. This determination is independent of any DC reductions of contrast such as may be caused by light leaks, corona fogging, or atmospheric haze. Deployment and use of standard resolution targets is also encouraged.

In order to determine the loss of contrast in C/M mission photography due to recurring serious corona difficulties and of other unwanted film exposure, it is desirable to remove the contrast reduction due to atmospheric haze alone. This is best done by flying a calibrated camera, using identical film and processing, in an aircraft at high altitudes over targets of known ground contrast at approximately the same time as the satellite engineering pass. This is not envisaged as a continuing test program but one to be terminated as confidence is gained that extraneous light is not fogging the film. Relative merits of different filters and slit widths could also be assessed by such a program once the airplane is flying.

C. Film Processing and Sensitometric Strips

1. Film Processing

No appreciable degradation of limiting resolution in the C/M photography was found to result from film processing. It does appear, however, that the processing has frequently been to a fuller level than that to which the mission is designed.

The exposure criteria are based on two series of experimental data collected from aircraft and aerial reconnaissance cameras. These data are further reviewed in the light of analysis of current operational results. We recommend resumption of a program to review exposure criteria and chemical processing and modification of procedures as found appropriate to maximize the final product quality. The exposure latitude of the film (higher D max) should be extended without adverse effect.

2. Sensitometric Strips

Sensitometric strips are controlled exposures which provide a calibration of the characteristics curve (density vs. log exposure) of the mission film. If desired as a monitor of film processing uniformity throughout a mission sensitometric exposures should be placed frequently along the edges. This is done most conveniently after flight exposure and just prior to processing. At present in view of corona and other non-image forming light problems, sensitometric strips are of uncertain value for this monitoring function. However, they appear to be attractive as an adjunct for edge measurements since sensitometric step wedges on each frame can be used conveniently for calibrating the microdensitometer and film combination out of the edge trace. In view of present uncertainties in high resolution edge scanning techniques and reliability, their trial evaluation is recommended.

D. Atmospherics

1. Calculation of Weather Effects

The transfer function of the atmosphere plays an important role in the considerations of each of the three preceding sections.

For example, in designing to a transfer function there ~~is~~ would be limited value ~~to~~ in striving for a lens transfer function which achieved a resolution substantially dulled by turbulence. Likewise if the DC haze filtering presents only objects of low contrast to the lens it is for such objects and not for high contrast ones that it is desirable to optimize the resolution.

The effect of turbulence on the transfer function is negligible on the scale of 10 ft. ground resolution photography (2×10^{-5} rad angle). However, there is appreciable contrast reduction as a DC effect of haze. This is very sensitively dependent on local weather and its degree of preditability over hostile territory is undetermined. There are suggestions that it may be correlated usefully with atmospheric humidity, which can be predicted with a measure of reliability and this study now in progress at Wright Field deserves ~~continuing~~ renewed support and encouragement. Analysis of atmospheric parameters in conjunction with the overflights discussed in B.2 will be useful in this study. Once it has been ascertained that the image contrast is determined primarily by haze and not by corona or light leaks, GEMS as discussed in A.2 ~~will be~~ may of value for ~~promoting a~~ measur~~e of~~ loss of contrast or modulation resulting from haze.

2. Prediction of Weather

The extent to which world-wide weather data as available from Program 417 can be integrated into the mission orbit selection to reduce the present average of roughly 50% cloud cover in the photography is explored but no conclusion reached.

COMPARISON OF VARIOUS METHOD OF IMAGE QUALITY MEASUREMENT

		Static Laboratory Test of Instrument	Dynamic Laboratory Test of Instrument	Operational Evaluation of Technical Performance	Operational Evaluation of Quality For Photo. Interpretation
1.	Sine Wave Targets	Good	Too much data compared to (3)	Targets too large	Limited
2.	Photometric Edge and Microdensitometers	Less Convenient and precise but related to (1) and (3)	Less convenient and precise but related to (1) and (3)	Good, more available than (3) But Less Precise	Value because Relationship to PI usefulness not known
3.	Three Bar targets	Good	Good	Good but limited by available * targets * requires photometric data	
4.	RES			Convenient but method and accuracy not validated	
5.	Photographic comparitors GEMS			Possibly good Precision not validated	May be of use as experience is gained.
6.	MIP				Good Subjective Judgment includes scale, haze, subject matter, illumination, etc.